Innovation and market dynamics: A two-mode network approach to user-producer relation

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Innovation and market dynamics: A two-mode network approach to user-producer relation

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Abstract

In this paper we propose a new mental representation of how markets, technology and their interaction concur in explaining the why of a certain innovation instead of another. We empirically test this theory in the telecommunication switches industry. We consider innovation as a new alignment of needs and opportunities, where markets and technology are not the sources, but the actors in this alignment process. In order to accomplish this task, we suggest proxies for technological opportunities, market needs, and, at the same time, for interactions of these two elements. We make use of a statistical tool that grasps the matching nature of this interactive phenomenon.

Keywords: user-producer interaction, two-mode network, telecommunication manufacturing industry.

JEL Classification: O30, O31, O33

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1 Introduction

The aim of this paper is to explain the why of a certain innovation instead of another as the result of the coevolution of markets and technology. In this paper we quantitatively overcome the long demand-pull vs. technology-push debate that turned out to be sterile (Freeman 1994). We pursue this task by addressing the role of coevolution of market and technology as explanantia of the occurrence of an innovative activity. Although this view is now well received among scholars (Malerba 2006), to our knowledge there are no attempts to empirically address this issue.

By looking at the existing literature, we claim that this lack of empirical exercises is due to the misleading mental representation of markets and technology as sources of innovation. On the contrary, both technology, as the realm of feasible technological opportunities, and markets, as the set of heterogeneous needs, should be considered actors that generate innovation by exploring the possible matches of their characteristics. This view was first put forward by Clark (1985), when describing a successful innovation as the result of a process of design creation. Design was there defined as the matching process of technological opportunities with consumers needs.

Thus, in order to empirically analyze how the coevolution of markets and technology acts upon innovation the problem is threefold: (1) to proxy technological opportunities and market needs at the same time, (2) to consider the interactions of these two elements, (3) to make use of a statistical tool which consider the matching nature of this interactive phenomenon.

Previous literature on the debate demand-pull vs. technology-push provided us with a vast list of possible proxies for markets and technology (among others Schmookler (1966) and Fontana and Guerzoni (2008) for markets, Nesta and Saviotti (2005) for technology). Also the role of interactions in the process of innovation has been extensively studied (Lundvall 1988, Lissoni 2001).

This paper contributes to the point (2) by providing a new outlook on user-producer interaction. In particular we employ a two-modes network approach to map and assess knowledge flows between various actors. Furthermore, the most innovative challenge of the paper is to address the point (3) and, thus, to empirically capture the matching nature of the process of innovation. In order to accomplish this task our base research question *"Why does an innovation emerge instead of an other ?"* becomes *"Why did an innovation, i.e. a new design, emerge from the specific characteristics of a producer/user dyad instead of an other?"*. The answer to this question requires a mental experiment where the observed reality is compared with all the possible alternative counterfactual realizations. Further on, we will discuss the econometric model and data structure that allow to perform this counterfactual analysis.

We use as test field the telecommunication switching industry where user-producer interactions play a predominant role. In fact, in this sector the production and the purchase of each switch requires the creation of a very customized product. Moreover, the technology rapidly changes over time together with both firms' competences and users' requirements. Therefore, each product is a new match between opportunities and needs in a process where not only the characteristics of users and producers matter, but especially their interaction. The econometric exercise is carried out using an original dataset about telecommunication manufacturers, network operators, and country characteristics.

The structure of the paper is the traditional one. Next section discusses the theoretical approach and its positioning in the literature. Section 3 describes the data and the variables used. Section 4 is devoted to a brief description of the industry and the network analysis of user-producer interactions. Finally section 5 presents empirical results on how the coevolution of technology and markets affects the likelihood of an innovation to take place instead of an another. Some final considerations conclude.

2 Aligning markets and technologies

A core research question in the discipline of economics of innovation deals with the nature of the prime drivers of the innovative activity. The traditional view suggests that market demand governs the rate and direction through monetary incentives. This idea dates back to the work of Gilfillan (1935) who surmised that there exists a tendency of technology to lag behind demand. His work opened up a stream of empirical research focused on testing the demand-pull hypothesis, that is that firms innovate to satisfy needs signaled by the demand (among others Schmookler (1966), Langrish et al. (1972)).

This view relies upon an unexpressed faith on technological progress: technology opportunities are thought as unlimited and inventors can explore them in any possible direction. Both sufficient and necessary condition is simply that there exists a latent demand granting adequate sales, profit, and returns on R&D investments. The set of all possible human needs, that is any latent demand for an innovative product, is thus conceived as a subset of the unbounded set of technological opportunities. A firm is expected to decrypt consumers' signals in order to place in the market the innovative product which meets their needs. For this reason this approach has been label "demand-pull".

This view has been strongly criticized by Mowery and Rosenberg (1979) and Dosi (1982). On the one side, they addressed the capability of demand to point out a direction for research: the demand-pull approach fails to separate demand from the "limitless set of human needs" (Dosi 1982). For this reason the main flow of all those studies consists of the "incapability of defining the why and when of certain technological developments instead of others and of a certain timing instead of other" (Mowery & Rosenberg 1979, p.229). Furthermore, Dosi points also out that R&D cannot freely explore an infinite space, but it is focused on specific technological problems and trade-offs which define the trajectory where the technological progress is moving along[1]. The conceptualization of the relationship between opportunities and needs is thus here reversed: the technological opportunities are a subset of the limitless

[1]Note that the concept of technological trajectories embraces much more than what is discussed here (Dosi 1982, Dosi 1997).

set of human needs, technology follows its own internal logic and demand can only select among all of the possibilities provided by firms.

As response to this critique, scholars refined the demand-pull approach and acknowledged that what matters is not a vague idea of demand, but rather the smaller set of needs of consumers with a high need determinatess (Teubal 1979, Clark 1985) or sophistication (Guerzoni 2010). Different concepts such as lead users (Von Hippel 1988), experimental users (Malerba, Nelson, Orsenigo & Winter 2007), pioneers (Rogers 1995) recognize the importance of those actors with highly defined preferences. In order words, they reduce the limitless set of human need to its much smaller subsets of needs of very specific users.

If we combine these streams of research, technological opportunities and users needs should be considered as two partially overlapping, but separated sets. Indeed there is no reason to assume that the two sets of opportunities and needs are either coincident (all and only all we want is feasible), or disjoint (only what is feasible is not wanted). Accordingly, it makes sense to consider the process of innovation as the attempt to align needs and opportunities (to want what is feasible and to do what is needed). In this view, markets and technologies cease to be a source of innovation but rather actors that try to match their characteristics.

Clark (1985) defines this process as design creation, where design is a fitness between a form and a its context. The context is the set of users needs to be satisfied and the form consists of the possibilities provided by a technology. When a new technology became available both consumers and producers tend to perceive it in terms of already existing products and, for this reason, they might ignore how to fully exploit its potential and which needs can satisfied. The process leading to a successful innovation is a process of learning through which producers and users became aware of opportunities, needs, and of their possible alignment (Clark 1985).

As already Freeman (1994) clearly pointed out, the debate demand-pull versus technology-push is sterile, but it is precisely the coevolution of technology and demand to be considered. Although Freeman's suggestion is reasonable and well received among scholars, few attempts have been made to operationalize this idea of coevolution in explaining successful innovation and to empirically assess it (Malerba 2006). We surmised that this is probably due to the fact that that markets and technology have still been treated as coevolving sources, rather than coevolving actors of innovation.

Based on this line of thought and bringing together different streams of research, we consider innovation as the result of a matching process of markets and technology characteristics. Thus we have three elements to take into account: (1) markets and technology characteristics as in the traditional literature, (2) the interaction among users and producers to grasp Freeman's idea of coevolution, and (3) the matching nature of the process.

2.1 Design as successful innovation

Markets and technology characteristics, their interaction, and the process of matching are three theoretically determined elements, which have to be translated in empirically operative tools. Based on previous literature we discuss here which proxies can be used. An extensive explanation about the derivation of all the variables used and the empirical method will be discussed in the empirical section of the paper.

Concerning the demand side, Schmookler empirically shows the size of a potential market is a good predictor of the future innovative activity in a sector (Schmookler 1966). Although his analysis suffered of statistical flows (Kleinknecht & Verspagen 1990), the overall results still hold and it is stronger for large industries (Scherer 1982) and for process innovation (Fontana & Guerzoni 2008). A second stream of research suggested that demand can pull innovation also by clearly signaling their needs and highlight the path R&D should go to strike the market with successful innovations. For this reason also heterogeneity and the level of users sophistication should be taken into account (Fontana & Guerzoni 2008).

On the technology side, two factors have been taken into account. Resource based theory (Penrose 1959) suggests that the search activity of a firm is driven by its knowledge stock, that is by its competences accumulated over time. The knowledge stock is a double-edged sword: the growth of new knowledge is positively correlated with the capabilities a firm has to acquire further knowledge and innovate (Kogut & Zander 1992); however, it also might became a source of rigidities and hinder innovation because firms tend to search only locally (among others March (1991) and Nelson and Winter (1982)). Secondly, knowledge proximity to the relevant technological trajectory of a sector might influence the rate and direction of a firm's innovative activities. The concept of technological trajectories as introduced by Dosi (1982) describes the existence of a pattern of certain problem solving activities, which are preferred to others or which have turn out to be more successful. This concept resulted to be very useful to depict the limited possibility of technological search, which is not unbounded, but proceed at least in time of "normal science" along and around a given trajectory.

From an empirical point view, scholars made an extensive use of patents to capture the idea of knowledge stock (Malerba & Orsenigo 1997) and its characteristics such as relatedness (Nesta & Saviotti 2005) and we will build upon these attempts. The empirical analysis of technological trajectories has mainly focused on the artifact level. For instance, product characteristics have been extensively used to grasp technology dynamics in aircrafts and helicopters (Frenken, Saviotti & Trommetter 1999), and tanks (Castaldi, Fontana & Nuvolari 2009). Only recently, works in patent or publication citation network analysis made finally possible to empirically capture the idea of technological trajectories at the knowledge level (Mina, Ramlogan, Tampubolon & Metcalfe 2007, Verspagen 2007, Martinelli 2011). Patent citations can be used to track flows of knowledge among patents and map in a network "chains of ideas as they develop over time" (Verspagen 2007). By looking at the intensity of citation among different patents in a citation network has been possible to identify in various industry a main path of knowledge flows, which has been interpreted as proxy for a technological trajectory. From a firm perspective, it is therefore possible to position firms in the technological space by looking at the distance of their patent portfolios to the trajectory (Bekkers & Martinelli 2011).

The process of matching between producers‘ technology opportunities and users’ needs takes place through interactions among the various agents. Evidence of this interaction is well established in the literature ranging from the active role of lead users (Von Hippel 1988) or local users (Lissoni 2001),the system of innovation (Lundvall 1988), to the co-production (Gallouj & Weinstein 1997). In this paper, we proxy the intensity of interaction with two different kinds of knowledge flows, a direct one and an indirect one. By direct knowledge we consider the knowledge exchange that takes place during an interaction where users learn about technological opportunities and producers about markets needs. Secondly, we assume that the knowledge developed during an interaction persists within the actors and it is carried on by an actor in any future relationships with third parties. In this way, we want to capture that both firms and users profit from the past experience of their partners as well.

Also in this second case, empirical evidence is well established. Especially in knowledge intensive industry, any workers make use of the knowledge gained in previous interactions with other agents (among others, see Den Hertog (2000)). We make use of citation network to capture both the direct and direct measures of interaction, which are going to be extensively discussed in the empirical section.

The third empirical issue does not concern the type of variables involved, but rather the model describing their coevolution. As put forward, in our view technological characteristics and needs have not to be considered as sources of innovation but rather elements to be aligned in order to produce innovation. Firms and users are the actors who actively make this alignment possible.

The question of why an innovation occurs instead of another can be thus rephrased as why a specific match of users needs and technological opportunities have been observed instead of another. In order to answer this question, one should observe all possible matches of users’ needs with producers’ technological opportunities and, thereafter, compare the cases which led to an innovation with those where it did not happen. However, an innovation *ex post* is the realization of a market-technology match **only** when the alignment between needs and opportunities took **successfully** place. In other words, the lack of observations of failures creates the problem of missing counterfactuals. The mental exercise that a researcher has here to perform to is to imagine “what if” scenarios and compare any possible characteristics of the technology with any other possible characteristics of the market. This paper proposes a methodology that allows to run this hypothetical counterfactual analysis. An assumption is however necessary, that is producers are repository of the technical knowledge, while users of the demand needs. We acknowledge the limitation of this assumption because both users are involved in the

R&D process and producers are, to a certain extent, aware of users needs. Nevertheless, the fact that we also take into account the role of interactions might mitigate the burden of this assumption. Thus, the empirical method proposed in section 5 considers all possible matches of users and producers and compares the characteristics of those matches that generated a new alignment of needs and opportunities with those where it did not occurs.

2.2 Hypotheses

Based on this elements we can now better specify the empirical hypotheses to be tested.

Hypothesis 1: Users' and producers' characteristics have a significant impact upon the likelihood of a successful innovation to come into being instead of another

Hypothesis 2: The level of interaction among users and producers has a significant impact upon the likelihood of a successful innovation to come into being

Hypothesis 1 acts here as control hypothesis and tries to capture past results from the literature. Demand is thus described by usual proxies for its size and complexity, while technology is captured by firms knowledge stock, and proximity to the technological trajectories. Hypothesis 2 captures the coevolving nature of the innovation process. The intensity of interaction is measured with network indicators and we test the role of both directed and indirected interactions.

As test bed for this hypothesis this analysis makes use the telecommunication switching industry[2], which is very appealing for our theory for several reasons. First of all, any installed switch is a complex and unique product resulting from the interaction between a manufacturer (the producer) and a network operator (the user). In this dyadic relation, the former has specific technical knowledge about technological opportunities, whereas the latter has specific needs because it manages the telecommunication infrastructure. For digital switching platforms, that are the specific product matter of this paper, manufacturers' competences relate to the trade-off between incorporating new components for increasing switch performance and keeping economic feasibility. For users, competences relate to demand expectations and infrastructure management. In particular, because network operators have an infrastructure characterized by a specific topology extremely costly to change[3], they have rather diversified needs: although different users might share some ideas about how end demand and final customers' preferences would evolve, they rely on different infrastructure systems. For this reason, overall, they achieve similar level of services using with various types of equipment. Moreover, the lock-in into different infrastructure topologies determines a long term demand for switches with different service characteristics and fosters

[2]Telecommunication switches constitute a fundamental part of the telephone network. It allowed the establishment of a phone call by realizing a connection from a selected inlet to a selected outlet for the duration of the call.

[3]For instance, once the local switch is installed and all the subscribers are connected, any relocation of the local switch is very expensive, unless a major network restructuring takes place.

a stable co-existence of different designs. Therefore, in this industry each installed switch is a peculiar design resulting from a unique alignment between users' needs and technological opportunities and, thus, in our definition, a successful innovation.

A second characteristic of the industry relevant to the analysis is the fundamental role of the downstream market. Being network operators very sophisticated, that is with very concrete and complex needs to be satisfied, not only they drive adoption and diffusion of new switching platforms, but also their research labs are a valuable source of knowledge. Starting from the flagship case of the Bell Laboratories, these laboratories would represent a source of science-based research necessary for the development of the latest switching platforms [4].

For concluding, the telecommunication switching industry is an ideal setting to understand how the coevolution of markets and technology affect the emergence of an innovation. Indeed, in this sector it is straightforward to pinpoint a new design, being any new installed switch. Moreover, not only a variegated technological base and a diversified demand plays a role, but also user-producer interactions.

3 Data, variables, and methods

The aim of this section is to provide the reader with a description of the data and variables used, and of the methods applied in section 4 and 5. As anticipated in the introduction the empirical analysis will include network analysis and a choice model (the multinomial conditional logit).

Following the hypotheses stated in section 2.2 we test three groups of variables. These are summarized in table 1 and discussed in section 3.1.1, 3.1.2, and 3.1.3, respectively.

[Table 1 about here.]

The dependent variable of the choice model, *i.e.* a successful innovation has been derived from the *Dittberner Digital Switches Evolution 2003 Report*, which consists of a census of all the existing digital switches installed between 1972 and 2001 and includes 3017 observations for 42 manufacturers. For each switch, it provides information about the producer (i.e. the manufacturer), the user (i.e. the telecom operator that bought it), the model, the capacity described as the number of lines, and the year of installation. From this data source, it is therefore possible to derive a dyadic relation between producers and users. This relation will provide the dependent variable for the econometric model and the base for the two-mode network analyzed in section 4.

Despite the richness of these data two issues emerge: first, the presence of several missing observations about the years of installation, and the lack of information about manufacturers acquired by other

[4] Other famous PTT laboratories are: the GPO Dollis Hill Research Centre in United Kingdom and the Electrical Communication Laboratory (ECL) established by NTT in Japan.

companies before 2001. In the first case, only 1627 switching installation can be actually assigned to a specific year. The distribution of the observations with missing year by firm is very skewed for some small manufacturers, however, they account for only the 36% of the whole world capacity[1]. The second issue has been partially solved with some reconstruction work by re-assigning the entry from the company that took over the business to the old ones. This was done by matching the switch model, which is firm specific, and the years. This worked rather well for the switch *System 12* installed before 1988 and re-assigned to ITT from Alcatel (that took over ITT); however, this process has been less precise in the case of GEC-Plessy where it was not possible to distinguish the two companies as they develop the switch *System X* together. Overall, it is worth to note that only 4 companies (ITT, GEC, Plessy and GTE) were acquired and, therefore the reconstruction work has still been very limited.

These market data are complemented with patent data, financial data, and country data in order to address the research questions of the paper. The merge of such different data sources cut the number of useful observations for the regression analysis because data refer to different time spans. The most incomplete database is OSIRIS, the financial one, for two different reasons: numerous manufacturers are not available and only few companies have long financial data series. The *Dittberner Digital Switches Evolution 2003 Report* points out the existence of two types of switches manufacturers: big companies, both with the status of national champions and with a more international outlook, and very small manufacturers having an exclusively local production. In the latter categories we can find manufacturers such as the Slovenian Iskratel, the Polish Inventel, and the Iranian ITRC. For this small manufacturers it was difficult to find any information both in specialized IEEE (Institute of Electrical and Electronics Engineers) publication and in the internet[2]. Fortunately, these manufacturers represent a tiny part of the whole market in term of shipped capacity as they were basically local producer serving small domestic markets. Summing up, the problem of skewed time series length is twofold: very few companies have financial data going back to maximum middle '80s and the majority of them have complete series only for recent years (especially Chinese manufacturers) but market share are available only to 2001. However, the analysis is based on almost the 50% of the entire population and possible bias either partially excluded by previous work on the subject (Martinelli 2011) or carefully taken into account.

3.1 List of variables

The variables used in the empirical analysis are reported in table 1 and can be grouped in three: Firms and Technological Characteristics (X), User-Producer Interaction (W), and User (Country) Characteristics (Z). These groups are summarized in the following subsections.

3.1.1 Firms and Technological Characteristics (X)

These variables capture firms' characteristics, such as size and technological competences. Financial data about manufacturers was retrieved using the OSIRIS Database. For each company it was possible to build a series about profitability, total assets, and number of employees. Firm size is measured using the total assets[3] deflated with PPI for capital goods.

Firm's technological competencies are evaluated with the firm's knowledge stock calculated using USPTO patents. Knowledge stock is proxied in the standard way with the perpetual inventory method and a depreciation rate of 15% (Hall, Jaffee & Trajtenberg 2000).

Firms' technological position is represented as relatively to the technological trajectory. The technological trajectory is identified by applying the connectivity approach to patent citation networks. Such approach links patents through their citations and maps the knowledge flows occurring between them. This method applies a search algorithm that identifies the "main path" within the patent citation network. This path is a set of connected patents and citations linking the largest number of patents of the network. Because a citation can be viewed as a knowledge flow, the main path is the path that cumulates the largest amount of knowledge flowing through citations in the network. This path represents therefore a local and cumulative chain of innovation consistent with the definition of technological trajectory put forward by Dosi (1982)[4].

This methodology has been successfully applied to several technologies such as cell fuel (Verspagen 2007), medical innovation (Mina et al. 2007), the artificial disc (Barberá, Jiménez & Castelló 2010), and switches (Martinelli 2011). Starting from the result of Martinelli (2011), the variable *Distance* measures the distance of the firm's patent portfolio from the patents belonging to the technological trajectory. In particular, the variable *Distance* is computed for each firm as the average geodesic distance between each patent in the firm's portfolio and the closest patent belonging to the technological trajectory.

Finally, the domestic dummy controls for the advantage to ship a switch to the domestic market. This variable should control for the tight institutional relation between manufacturers and producers during the pre-liberalization period.

3.1.2 User-Producer Interaction (W)

In this group of variables we consider the direct and indirect interactions between users and producers[5]. These variables are built analyzing the two-mode network of manufacturers and operators and its unipartite projection.

A two-mode network is characterized by the presence of two types of nodes which cannot be directly connected. Figure 1 shows an example of two-mode network where the blue squares represent manufacturers and the red circles network operators. Indeed, these two types of nodes cannot be directly linked because manufacturers can ship switches only to operators and not to other manufacturers. The thickness of the ties is proportional to the number of lines installed by a manufacturer into the network operator's infrastructure.

[Figure 1 about here.]

The value of the tie represents the strength of the direct interaction between a manufacturer and a network operator. From the manufacturers perspective, it measures the experience and the knowledge cumulated about a specific user and its network infrastructure.

We can draw a two-mode network for each year in the sample. Therefore, we can build a balanced panel dataset whose individual (the cross-sectional) dimension is the dyadic relation between the user and producer. The variable *DirExp* measures the stock of such direct interaction and it is calculated using the perpetual inventory method and a 15 % depreciation rate[6] on the number of lines (i.e. the strength of the tie in the above figure) a producer has sold to a user.

In a two modes network, the adjacency matrix, which describes the link among nodes, is not necessarily a squared matrix because the number of the two types of nodes is not necessarily the same. For this reason, descriptive analysis techniques such as centrality measures cannot be computed. A standard procedure is therefore to focus on its unipartite projection that contains only manufacturer nodes, which are linked if they share common users.

[Figure 2 about here.]

For instance, figure 2 shows the unipartite projection for the manufactures displayed in the two-mode network in figure 1. Links between manufacturers are established in case of common "users" such as between Lucent and Alcatel which are connected because they both ship switches to France Telecom; similarly, no link exists between Lucent and Siemens. Ties are weighted using the minimum, that is, if Lucent and Alcatel supply France Telecom 100 and 140 lines respectively, the value of the link between the two manufacturers will be 100. In this way, the link between the two manufacturers represent the minimum bundle of indirect knowledge they can gain from having the same users.

In the similar fashion as before, we can obtain an unipartite network for each year and build a balanced panel data whose individual dimension is the manufacturer. In this panel data, we can include for each year the sum of the values of the ties of each manufacturer that correspond to the manufacturer's degree centrality in the unipartite network. This corresponds to the total indirect knowledge that a manufacturer gains every year by sharing a common pool of users. The intuition behind is the transitivity of the learning-by-interacting. In this specific context, the nature of this common knowledge is about how to adapt the existing switching platform to the user specific needs, expectations, and infrastructures. If on the one hand, this knowledge is "user-specific" on the other hand it goes to enrich the firm's competences. The variable *IndExp* is the stock of this indirect knowledge and it is computed using the perpetual inventory method with a 15%[7].

It is important to stress that all the networks analyzed in section 4 are unipartite projection obtained as just explained for specific years.

3.1.3 Users Characteristics (Z)

Finally, Z variables should capture the dimension of the demand side. The literature about demand and innovation can be divided in two stream. On the one hand, many authors (Schmookler 1966, Scherer 1982) put forward, discussed, and tested the role of demand as incentive: the larger is a potential market, the higher are the expected returns from an innovation, and, for this reason, the higher is the optimal level of R&D investment. However, since the work by Gilfillan (1935) clearly emerge the role of demand as provider of information. Due to the uncertain nature of the innovation process is very hard to predict expected returns from an innovation. Thus, users, especially in business-to-business relation can provide the inventors with useful information or even with prototypes. More recently, it has been put forward that not all users dispose the competencies to generate such information, but only those users with specific characteristics such as the sophisticated users (Guerzoni 2010), pioneers (Rogers 1995), lead users (Von Hippel 1988), experimental users (Malerba et al. 2007). In this paper we use countries data elaborated by the World Bank to portray the drivers of digital equipment demand and users characteristics. Following the literature, the proxies considered are GDP, the size of the installed switch, the percentage of the urban population, and the contribution of service sector to GDP (Shampine 2001, Greenstein, McMaster & Spiller 1995). GDP and the size of the installed switch capture the size of the market. Whereas, the percentage of urban population and the percentage of service on GDP are proxies for the complexity of the demand. We assume that the higher is the complexity of a market, the higher is also the sophistication of the users that needs switches. Despite their simplicity, these indicators capture the two main drivers of switching demand: network expansion and upgrading (i.e. sophisticated demand).

4 The telecommunication switching industry: a network approach to the user-producer relation

The aim of this section is to introduce the industry under examination and to discuss the evolution of the user-producer interaction using the unipartite network introduced before.

A practical advantage of studying the telecommunication switching industry is the limited number of producers that allows for a meaningful integration of quantitative and qualitative information and the possibility to apply the empirical strategy explained in section 5. As already explained in section 3.1.2, in this network a link between two manufacturers indicates the presence of a common pool of knowledge derived from sharing the same users.

The dataset used in this study allows to trace all the successful innovation resulting in the installation of a digital switch worldwide between 1972 and 2001. Table 2 summarizes the size of the two-mode network (i.e. number of manufacturers and network operators), and countries included in the dataset for two subsequent sub-periods and the whole dataset.

[Table 2 about here.]

Digital switches are increasingly produced by manufacturers and adopted by network operators and countries. The last columns in the table inform about the distribution of number of countries served by each manufacturer. Such distribution has a large standard deviation indicating the coexistence of manufacturers serving either a very limited or a large number of countries.

Table 3 and table 4 present figures about the evolution of the network size and key structural indicators for both each subperiod considered and the total network. The strength of the ties represents the stock of common experience derived by sharing the same users. This corresponds to the $IndExp$ presented in section 3.1.2, in the year 1990 and 2001 respectively. The total network includes all the installed lines with missing years that are assigned to the last period. This brings about an overestimation of the strength of the ties as none of these lines is depreciated[8].

[Table 3 about here.]

The comparison between the first two rows shows that more manufacturers start producing digital switches, however the value of the ties decreases both at the mean and at the maximum. This patterns is consistent with the mature and even declining phase of the technology in the 1990s. In fact, with the increasing demand of data transmission related to the diffusion of Internet, digital switches became obsolete. The last column indicated the cut-off point for the value of the ties displayed in figures 3, 4, and 5.

[Table 4 about here.]

Table 4 reports the evolution of some structural indicators of the network[9]. The decrease in the density of the network over time is consistent with the decrease of the value of the ties of time. This happens both because earlier common pool of experience depreciates and also because not many new lines are installed. The average distance between manufacturers is rather short and a very small proportion of the nodes cannot be reached. Finally, the GINI coefficient measures the dispersion of the values of the ties. This rather high and stable over time indicating that most of the successful innovation takes place from the interaction between few users and producers. This is even more evident when all the switches in the sample are included in the network.

Figure 3, 4, and 5 visualize the unipartite networks. They allow evaluating not only the whole network structure but also each individual firm and the underlying core-periphery structure. In particular, companies marked with red circles belong to the core, whereas the blue squares are in the periphery[10].

[Figure 3 about here.]

The network displayed in figure 3 shows the situation in the early phase of the industry. Even if the first digital switches were sold in the early 1970s, it is only some years later in 1979 that they emerge as the standard product and technology. The fitting of a core-periphery structure[11] allows to distinguish between companies densely linked from the others. The companies in the core are all large manufacturers, whereas in the periphery we can notice the coexistence of both large manufacturers (Lucent, NEC, and Nortel) and domestic producers (Tropico for Brazil, Italtel for Italy, C-DOT for India, ITRC for Iran, etc.). The fact that Lucent[12] does not belong to the core can be puzzling if we consider that Bell Laboratories, which belong to Lucent, were the most active research centre for telecommunication switches. However, because of the monopolistic position of AT&T as a network operator, its manufacturing branch, Western Electric was not allowed to sell to others operators until 1984 (Noam 1992). Therefore, the fact that user-producer interactions on a large scale are a "recent" phenomenon for Lucent in the period under examination can explain its secondary position in the network structure.

On the contrary, looking also at the strength of the ties we can notice the central role played by Ericsson and ITT. Both these companies have been characterized by their international outlook either because their domestic market was too small to provide the scale needed to support the R&D effort (Ericsson) or there was not a preferential domestic market (ITT).

Finally, observing the structure of the network, two groups of highly connected companies should be highlighted: the one on the right side including LG, HanWha, and Samsung, and the Japanese manufacturers on the left side (OKI, Hitachi, Fujitsu, and NEC). In the last case, the presence of reciprocal connections is the result of specific industrial policies aimed to develop and foster a telecommunication sector that brought the four Japanese manufacturers in a coordinated competition regime: they were collaborating at the Electrical Communication Laboratory (ECL) in exchange of fixed domestic market shares, but, at the same time, they were fiercely competing for foreign markets.

[Figure 4 about here.]

Figure 4 displays the same network for the next period. The visual comparison with the previous one points out an increase in the number of triadic closures and therefore an increase in centralization. The number of firms included in the core increases and numerous Chinese manufacturers (Huawei, Zhongxing, and Great Dragon) entered the sample. This is consistent with the fast catching-up experienced by Chinese firms in the telecommunication sector (Mu & Lee 2005). The entrance in the core of Nortel is the consequence of its aggressive strategy into digital switches probably due to the domestic market size (Canada) insufficient for the scale intensive R&D efforts. For this reason, Nortel successfully entered bot the US and the Japanese market (Sutton 1998, Fransman 1995).

[Figure 5 about here.]

The last figure (Figure 5) represents the unipartite network calculated on the whole sample, including observations with the missing years (see footnote 1). In this respect, it is difficult to interpret such figure where all the shipment for which we do not know the year became predominant as not discounted. This might explain why a company such as GTE belongs to the core and Nortel not. However, the MDS[13] layout used for network visualization tends to place close nodes, that have the most similar shortest distance. In this industry, they are manufacturers that share most of the pool of users. Despite the overestimation of the weights of the ties, it is still however possible to distinguish a group of highly similarly connected firms.

Overall, the network analysis points out the presence of two types of manufacturers: the ones involved in successful interaction with the same large number of users and the ones that do not. The implication is that only few companies can actually benefit from the sharing of the common pool of indirect experience.

5 Econometric model: a choice model[14]

In order to test the hypotheses put forward in section 2.2 this section estimates the probability of a successful innovation, where "success" is determined by the alignment between user needs and technological feasibility. The idea of alignment is operationalized through the estimation of the probability of a manufacturer to supply a switch to a specific network operator conditional to the independent variables. From the two-mode network perspective (see figure 1), this corresponds to estimate the probability to observe a tie between a network operator and a specific manufacturer instead of an other. In this respect, the estimation of our hypothesis corresponds to implement a mental experimental which considers all the possible alternative events that did not take place and we compare the characteristics of those events with the reality. This can be done by reshaping the data structure and transforming the data in a *choice* file[15], where each original observation (the installation) is multiplied by the number of alternatives (the number of companies that can supply the switch). In this *choice* file, the independent variables of interests can be of two types: alternative dependents or alternative invariants. The former group includes the variables that depends on the manufacturers (i.e. the alternatives) such as the variables in group X and W, whereas the latter includes variables related to the characteristic of the switch or the country (i.e. constant along the alternatives) such as the variables in the group Z.

In order to include both types of variable we need to rely on a mixed logit and in particular on a multinomial conditional logit. The probability of installation i to be shipped by manufacturer j is:

$$Pr[y_i = j] = \frac{\exp\left(\alpha X_{ij} + \beta W_{ij} + \sum_{l=1}^{42}(\gamma_l d_{ijl} + \delta_{Zl} dZ_{ijl})\right)}{\sum_{k=1}^{42} \exp\left(\alpha X_{ik} + \beta W_{ik} + \sum_{l=1}^{42}(\gamma_l d_{ijl} + \delta_{Zl} dZ_{ijl})\right)}$$

where d_{ijl} is a dummy variable equal to 1 if $j = l$ and equal to zero otherwise, $dZ_{ijl} = d_{ijl} Z_i$, and the number of alternatives (i.e. the number of possible manufacturers) is 42[16].

According to the literature, the model is estimated as a conditional logit with the inclusion of manufacturers dummies and their interaction with the alternative independent covariates (Cameron & Trivedi 2005). As for these multinomial models the interpretation of the coefficients is rather problematic, all the coefficients reported are marginal effects. In particular, for the alternative independent variables these marginal effects are calculated as:

$$\frac{\partial P_{ij}}{\partial Z_i} = p_{ij}(\beta_j - \overline{\beta}_i)$$

where $\overline{\beta} = \sum_l p_{il}\beta_l$ is a probability weighted average of β_l.

The main conceptual assumption of this model, that each company had the same probability to supply each switch, could be questionable. However, at least for large companies, which are the only one finally included in the model, the assumption seems reasonable.

Table 5 and table 6 show descriptive statistics and correlation coefficients of the dependent and independent variables.

[Table 5 about here.]

[Table 6 about here.]

Table 7 reports the first group of regressions. In the first column OLS results are shown; however, because of the nature of the dependent variable it can be used only as exploratory analysis. The last three columns display results of conditional logit regressions, where no alternative invariant covariates (*i.e. SwSize, GDP, Urban, and Service*) are included. All covariates have significant coefficients; specifically, the size (*LnAssets*) of a producer exhibits an inverted U shape impact on the probability that an interaction takes place. The variables related to firms' technological competences are significant and have the expected sign. The same is true for both interaction variables. Finally, domestic companies have an advantage over foreign companies.

[Table 7 about here.]

[Table 8 about here.]

Regressions displayed in table 8 include also the alternative invariant variables (i.e. *SwSize, GDP, Urban, and Service*) interacted with “alternative dummies” (i.e. manufacturer dummies). The focus is on the subset of large firms in term of shipment and telecommunication, because of the large number of alternatives (42) and the large number of companies with few valid observations (see appendix C). In addiction to that and following the results of the network analysis, only a limited number of companies have the possibility to compete for each shipment. The five models in the table differ in the alternative invariant variables and in the presence of the domestic dummy.

The results look rather stable at the different specifications. Size is not significant and this is expected as the focus is on large firms. Moving to the technology related variables (X), knowledge stock is positive and significant. Firm’s distance from the technological trajectory is negative and significant: reducing the distance of a company to the pool of relevant knowledge, increases the probability of observing a successful innovation. The user-producer variables (W) turn out to be positive and significant. Not only knowledge gained through directed interaction plays a role, but also the knowledge conveyed by users from past interactions with third parties. Finally, the domestic dummy is positive and highly significant revealing the advantage of domestic firms.

The last set of variables (Z) tests the impact of demand. As these variables enter as interaction with manufacturer dummies, we have to compare the alternative marginal effects. Figure 6 reports the average marginal effects for the four variable considered and shows the advantages of some firms in markets with specific characteristics.

[Figure 6 about here.]

In term of size of the market Nortel and Lucent display the largest advantage. On the contrary, Alcatel, Siemens, and Ericsson are more successful in smaller markets. A similar pattern is followed when controlling for the incidence of the service sector on the economy, for the size for the switch and for the percentage of urban population. The reason why a firm shows more advantage in certain market condition has to do with institutional and historical factors, which, although of a great interest, are not subject of this paper. Regarding the issue matter of this work what really emerge is that demand conditions have statistically significant impact on the likelihood to observe a certain new design.

[Table 9 about here.]

As robustness check, table 9 displays that estimated probabilities match the observed frequencies.

Finally, the multinomial conditional logit relies on the crucial assumption of independence of irrelevant alternatives (IIA). IIA implies that adding or changing alternatives do not affect the relative odds between the other alternatives considered. In general, this implication is not realistic for applications with similar alternatives, which is not our case. Moreover, we could rejects the null hypothesis, that different models with less alternatives are statistically different. Furthermore, the estimation of a multinomial probit (that relax such assumptions) shows comparable results.

Recalling the hypotheses stated in section 2.2, it is possible to conclude that the empirical model supports both of them. Within a framework where the innovation process is conceived as an attempt to match needs and opportunities both demand and technology show a significant impact. Moreover, also when controlling for users and producers characteristics the interaction of this two actors remain positive and significant. Demand, technology, and user-producer interaction are significant predictors of a successful innovation. The ranking of their importance requires further empirical research and it probably differs across sectors.

6 Conclusions

This paper suggested both a theoretical framework and an empirical method to overcome the debate demand-pull vs. technology push by looking at the coevolution of markets and technology. Although this view is somehow acknowledged in the discipline, there are no empirically exercises coherently moving in this direction. In this work we stressed the fact, that not only markets, technology, and their interactions should be simultaneously taken into account, but also the mental representation of markets and technology as sources of innovation has to be reconsidered.

The main contribution of this paper is twofold. First, this work proposed a new mental representation of how markets, technology and their interaction concur in explaining the why of certain innovation instead of another. Both technology, considered as the realm of feasible technological opportunities, and markets, as the set of heterogeneous needs, should not be considered sources, but rather actors, which by exploring the possible matches of their characteristics generate innovation. In this framework we attempt to explain innovation as the occurrence of a specific match between opportunities and need and we analyze the why of certain match instead of another. Answering this question correctly should require the mental experiment of comparing the characteristics of a match with those characteristics of all other possible ones that did not take place. Of course, this approach can be empirically pursued only in circumstances where the set of possible alternatives is not only finite, but also small.

Secondly, the paper suggested how to empirically deal with this issue. Section 3 showed how to grasp the idea of interaction with the use of two modes network. Both direct and indirect interactions can be proxied and analyzed in this framework. Section 5 showed how it was possible to use all the variables explained to perform the mental experiment described above and model an innovation as the successful alignment between needs and opportunities as opposed with all the possible counterfactual alternatives.

In this way, it was possible show the impact that the markets and technologies have on the probability that an innovation takes place instead of another. We accomplished this task by estimating the likelihood of observing a specific purchase in the telecommunication switches industry as the result of users and producers characteristics and of their interactions. Indeed, any installed switch is a complex and unique product resulting from the interaction between a manufacturer and an operator. In this dyadic relation, the former has the specific technological knowledge about opportunities, whereas the latter has specific needs. Therefore, each installed switch can be considered a new design. We run a fixed effect logit where the econometric challenge has been to simultaneously considering covariates varying across alternative and alternative invariants.

Results support our theoretical framework and suggest that markets and technologies significant impinge upon innovation within a framework where they are not considered sources, but rather the engine behind the alignment of needs and opportunities.

Notes

[1]Furthermore, some tests for selection bias were performed and if on the one hand the switches whose installation year is missing are on average smaller this difference is not statistically significant (with a p-value of 0.58) (Martinelli 2010).

[2]One exception is a short article *"Unknown switches?"* published on Global Communications Newsletter (Jajszczyk 1995).

[3]The total assets is the sum of total current asset, long term receivables, investments in unconsolidated companies, other investments, net property, plant and equipment and other assets, including intangibles.

[4]more technical details about the method are in Martinelli (2010)

[5]For a similar approach applied on a different case see Leiponen (2008).

[6]Results hold also with different depreciation rates (such as 5% and 20%).

[7]Results hold also with different depreciation rates (such as 5% and 20%).

[8]See footnote 1 for a discussion of the implications.

[9] For the definitions of the indicators exposed in the table see Appendix A.

[10]For the details about how the core-periphery model is fitted see Appendix B.

[11]See appendix B for details and the numerical results.

[12]Here Lucent indicates what in the past was AT&T and Western Electric.

[13]MDS stays for multidimensional scaling and it is a standard social network analysis technique

[14]All the estimations (and post estimation statistics) are carried out using the **asclogit** package available for STATA.

[15]The *choice* file is built following the instruction by John Hendrickx provided at `http://home.wanadoo.nl/john.hendrickx/statres/mcl/stata/mcl.pdf` .

[16]The whole population of the telecommunication switch manufacturers include 42 companies, however, not all of them enter in the regression analysis because of the lack of financial information.

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A Summary of key measures for the analysis of the knowledge network

[Table 10 about here.]

B Core-Periphery analysis

This annex reports the results obtained in fitting a core/periphery model. The procedure here used maximizes the correlation between the permuted data matrix and an ideal structure matrix consisting of ones in the core block interactions and zeros in the peripheral block interactions.

[Table 11 about here.]

[Table 12 about here.]

C Alternative summary statistics

[Table 13 about here.]

Figures

Figure 1: A two-mode network. An example.

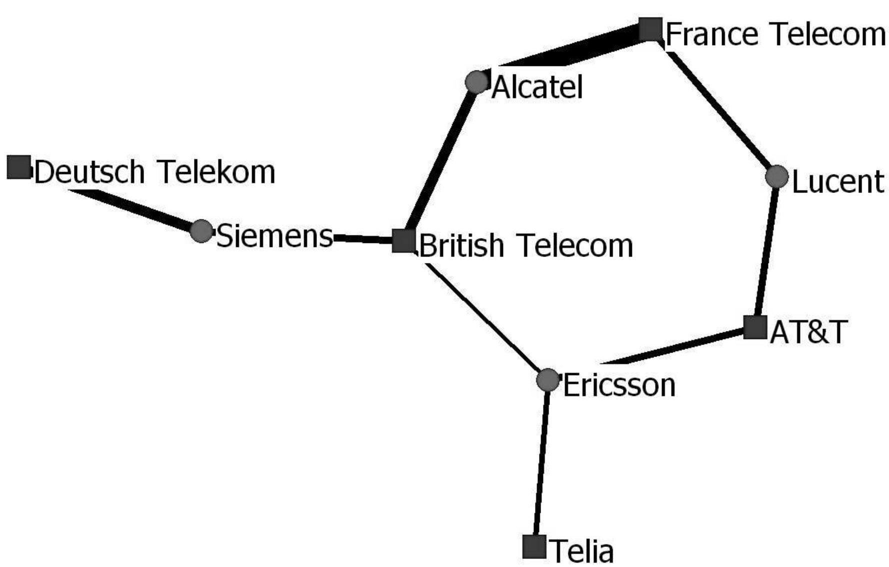


Figure 2: Unipartite projection. An example

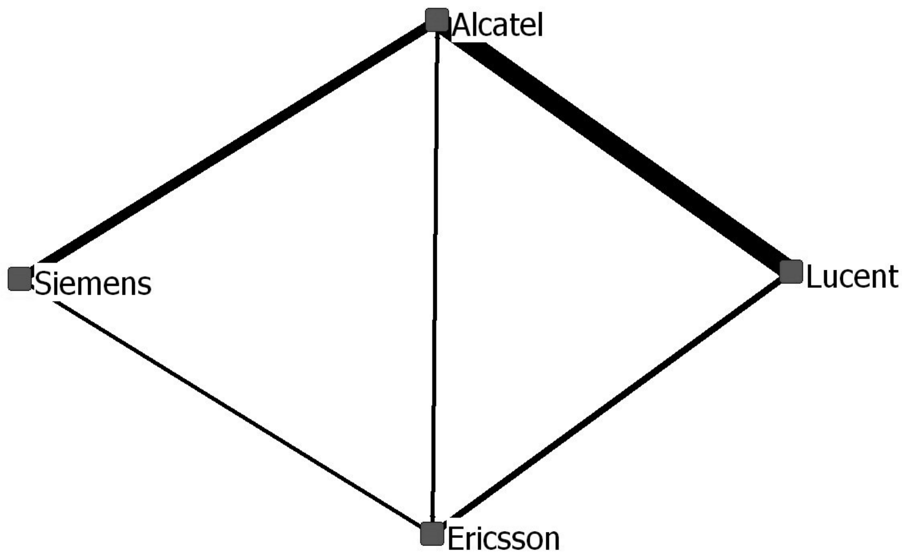


Figure 3: Network Evolution 1972-1990

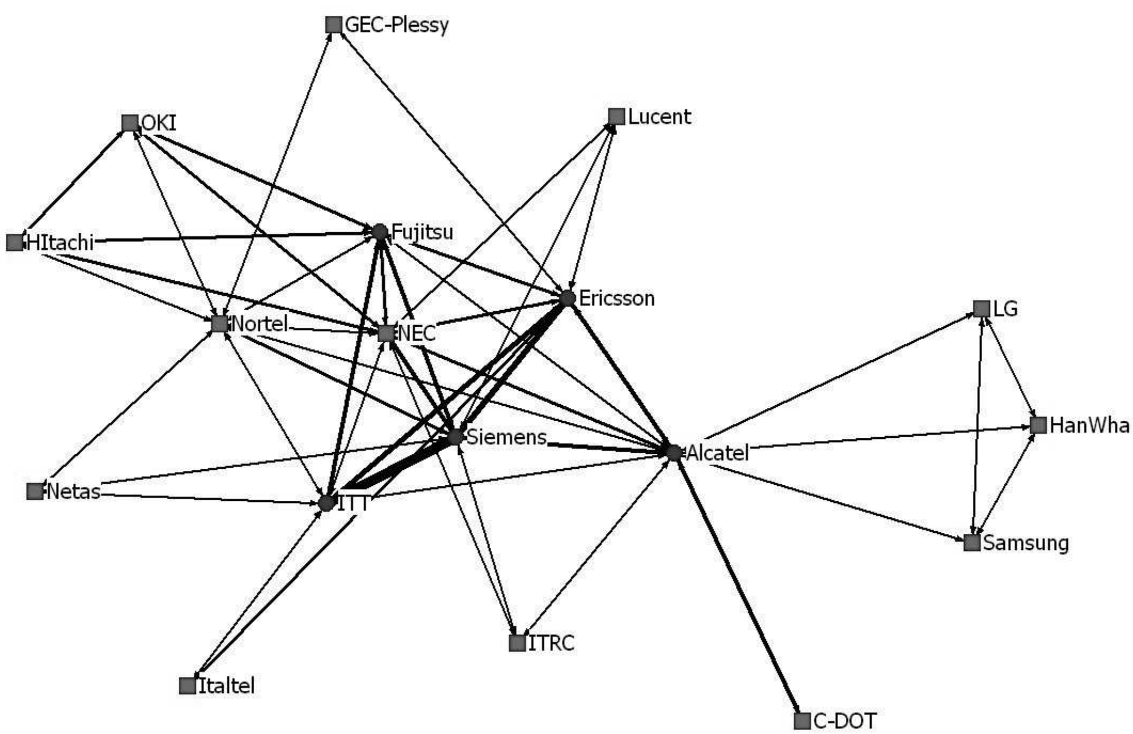


Figure 4: Network Evolution 1972-2001

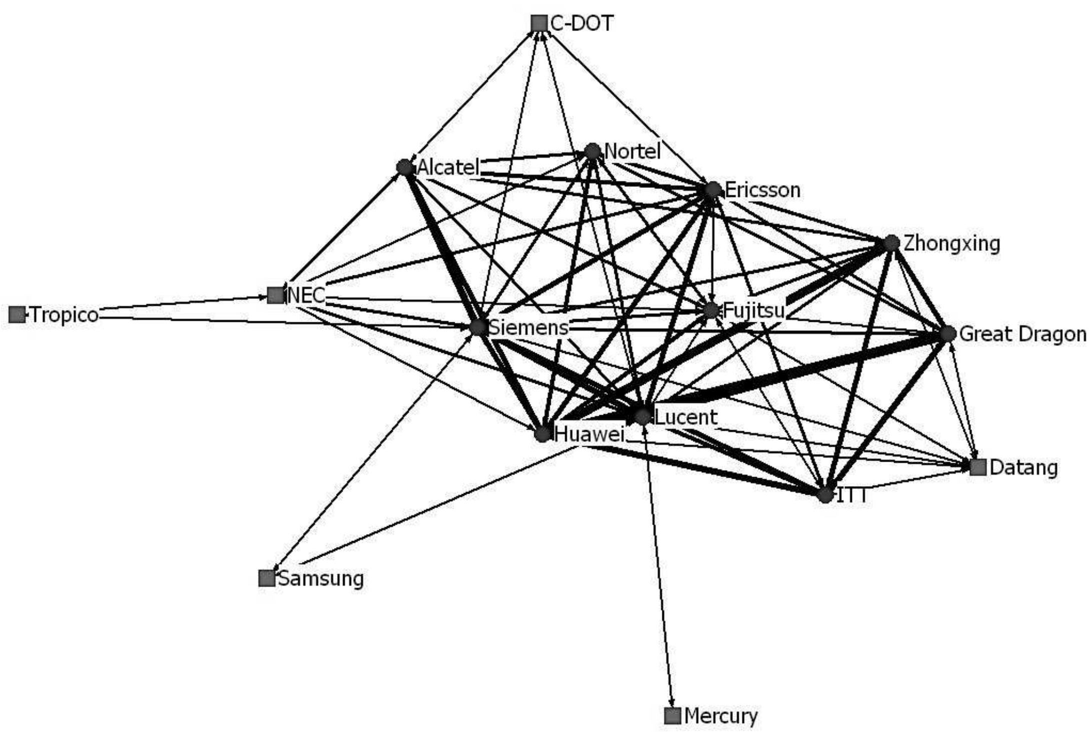


Figure 5: Network Evolution (Total)

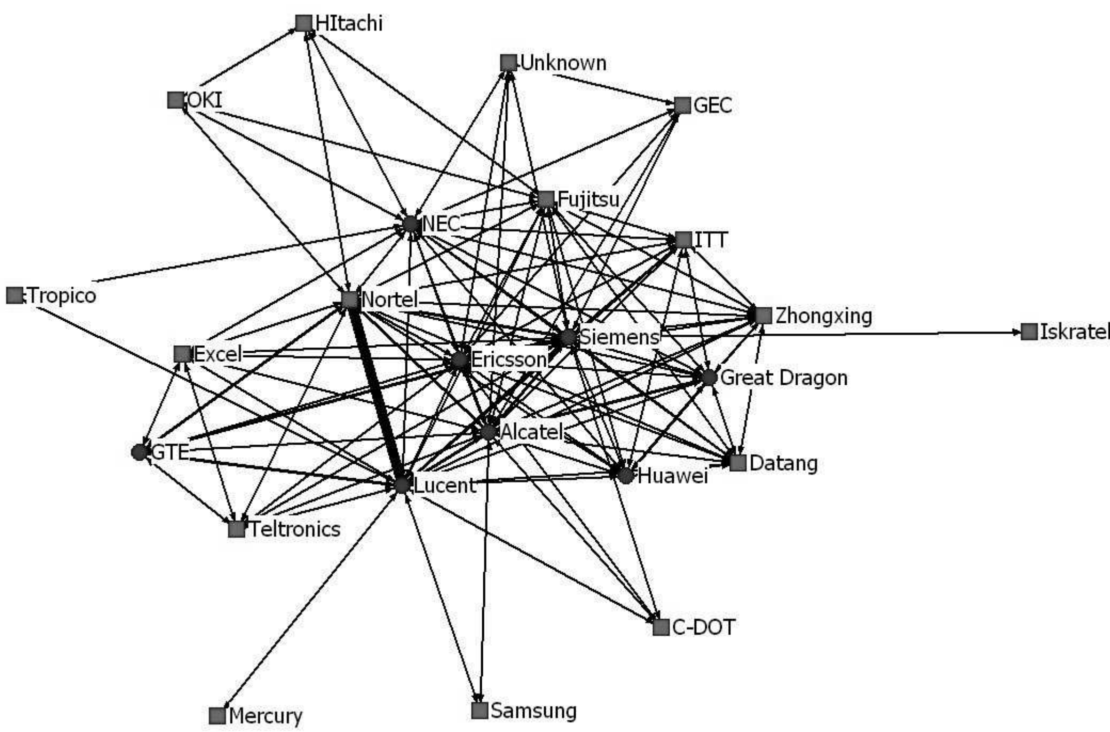
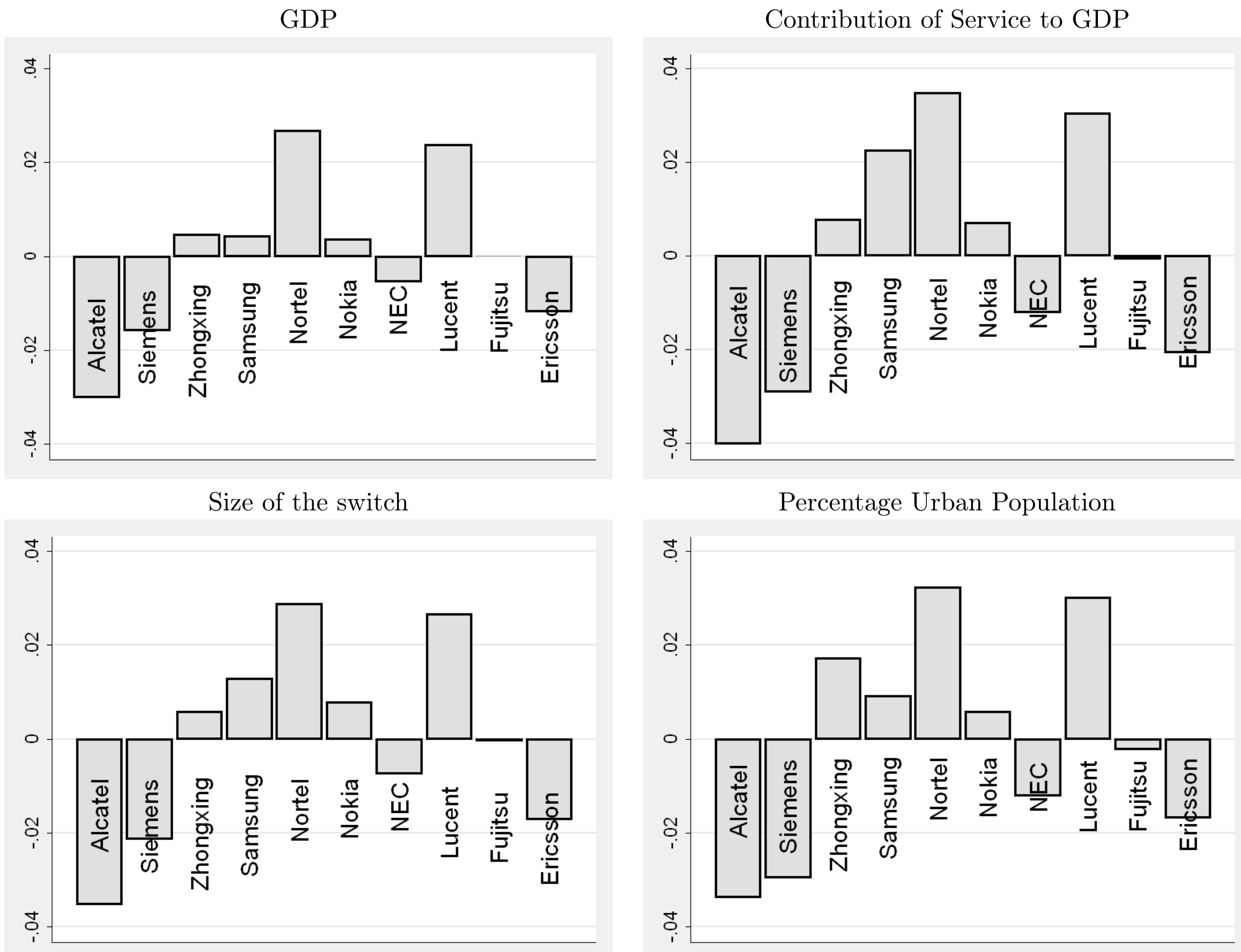


Figure 6: Average marginal coefficients for alternative independent variables (model 4)



Tables

Table 1: List of variables and hypothesis

Group	Category	Variables	Name	Hypothesis
X	Firms and Technological Characteristics	Size Knowledge Stock Distance Domestic dummy	*LnAssets* *LnKnow* *Distance* *Domestic*	1
W	User-Producer Interaction	Direct Experience Indirect Experience	*DirExp* *IndExp*	2
Z	User (Country) Characteristics	GDP Switch Size % Urban population % of Service on GDP	*GDP* *SwSize* *Urban* *Service*	1

Table 2: Network summary - Nodes

	Number of manufacturers (producers)	**Number of operators (users)**	**Number of countries**			
			Mean	Std. Dev.	Min	Max
1972-1990	29	183	10.79	16.67	1	70
1972-2001	39	525	17.667	27.64	1	123
Total[a]	42	750	20.714	31.5	1	134

[a]Total includes also the observations with missing year. See section 3 for details.

Table 3: Network summary - Size and Strength

	Number of manufacturers (producers)	**Strength of the ties (thus. lines)**				**Cut-off**
		Mean	Std. Dev	Min	Max	
1972-1990	29	14794.93	21249.02	0	82370.2	1000
1972-2001	39	12848.74	17539.04	0	62168.62	1000
Total	42	48304.85	89826.3	0	403603.4	1000

Note: Symmetric network

Table 4: Network summary - Structural indicators

	1972-1990	**1972-2001**	**Total**
Density	528.3904	338.1246	1178.167
Average Distance	1.675	1.388	1.305
Fragmentation	0.069	0.051	0.048
GINI Coefficient	0.655	0.66	0.748

Note: Symmetric network

Table 5: Summary Statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
$Response$	0.024	0.152	0	1	54222
$LnAssets$	16.247	4.668	0	25.035	19903
$LnAssets^2$	285.762	154.412	0	626.772	19903
$LnKnow_{t-1}$	3.534	3.383	0	9.056	37232
$Distance$	20.265	14.004	1	56.783	38005
$DirExp$	17.92436	307.0203	0	23486.12	54222
$IndExp$	2219.046	3627.119	0	17301.27	54222
$TotPort$	1077.068	4015.604	0	75199.398	54222
$LnGdp$	25.172	2.691	17.198	29.941	49560
$Service$	50.582	14.649	4.141	85.858	46032
$Urban$	55.035	23.618	5.22	100	53760
$Domestic$	0.039	0.195	0	1	54222

Table 6: Correllation Table

	Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	*Response*	1.000									
2	*LnAssets*	-0.040	1.000								
3	$LnKnow_{t-1}$	0.104	0.392	0.415	1.000						
4	*Distance*	-0.079	-0.189	-0.241	-0.426	1.000					
5	*DirExp*	0.148	0.009	0.009	0.039	-0.027	1.000				
6	*IndExp*	0.186	-0.013	-0.024	0.348	-0.258	0.088	1.000			
7	*TotPort*	-0.000	0.003	-0.002	0.028	0.031	0.041	-0.028	1.000		
8	*LnGdp*	-0.000	-0.017	-0.006	-0.034	-0.075	0.013	0.031	0.077	1.000	
9	*Service*	-0.000	-0.005	-0.008	0.004	-0.128	-0.011	-0.031	-0.093	0.269	1.000
10	*Urban*	-0.000	-0.001	-0.003	0.004	-0.070	0.003	-0.019	-0.044	0.245	0.700

Table 7: Regression Results

	(1) **OLS**	(2) **Clogit**	(3) **Clogit**	(4) **Clogit**	(5) **Clogit**
LnAssets	0.002	0.059	0.146***	0.133***	0.132**
	[0.002]	[0.035]	[0.037]	[0.040]	[0.041]
$LnAssets^2$	-0.000***	-0.005***	-0.007***	-0.006***	-0.006***
	[0.000]	[0.001]	[0.001]	[0.001]	[0.001]
$LnKnow_{t-1}$	0.008***	0.212***	0.173***	0.096***	0.093***
	[0.001]	[0.018]	[0.018]	[0.019]	[0.019]
Distance			-0.038***	-0.022***	-0.022***
			[0.003]	[0.004]	[0.004]
DirExp				0.001***	0.001***
				[0.001]	[0.001]
IndExp				0.001***	0.001***
				[0.001]	[0.001]
Domestic					0.671***
					[0.172]
Constant	0.013				
	[0.013]				
Observations	18766	13360	13360	13360	13360
R^2	0.012				
Pseudo R^2		0.048	0.082	0.148	0.151

Standard errors in brackets

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Regression Results

	(1) Mult.Clogit	(2) Mult.Clogit	(3) Mult.Clogit	(4) Mult.Clogit
LnAssets	-0.733*	-0.358	-0.625	-0.361
	[0.325]	[0.355]	[0.328]	[0.360]
$LnAssets^2$	0.037*	0.020	0.032*	0.021
	[0.015]	[0.017]	[0.015]	[0.017]
$LnKnow_{t-1}$	0.093*	0.103*	0.092*	0.100*
	[0.042]	[0.049]	[0.043]	[0.050]
Distance	-0.019***	-0.017**	-0.019***	-0.018**
	[0.005]	[0.005]	[0.005]	[0.005]
DirExp	0.002***	0.001***	0.002***	0.001***
	[0.001]	[0.001]	[0.001]	[0.001]
IndExp	0.001**	0.001*	0.001**	0.001*
	[0.001]	[0.001]	[0.001]	[0.001]
Domestic				0.650*
				[0.312]
LnGdp	Yes	Yes	Yes	Yes
TotPort	Yes	Yes	Yes	Yes
Service		Yes		Yes
Urban			Yes	Yes
ll	-1106.911	-963.532	-1076.065	-939.338
Observations	5281	4770	5281	4770

Standard errors in brackets
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9: Alternative summaries for regression 5

Company Alternative	**Cases Present**	**Frequency selected**	**Percent selected**	**Estimated probability**
Alcatel	589	112	18.57	0.142
Ericsson	543	66	10.95	0.104
Fujitsu	515	24	3.98	0.04
Lucent	372	69	11.44	0.173
NEC	515	31	5.14	0.055
Nokia	596	43	7.13	0.051
Nortel	573	121	20.07	0.195
Samsung	365	32	5.31	0.037
Siemens	576	99	16.42	0.153
Zhongxing	126	6	1.00	0.05

Table 10: Summary of key measures for the analysis of the knowledge network

Variable	Definition
Density	The density for a valued network is defined as the sum of all the values divided by the number of possible ties.
Average distance	The average of geodesic distances between nodes in the network. The distance is the length of a geodesic between them, which is measured as the shortest path.
Fragmentation	Proportion of nodes that cannot reach each other.
GINI Coefficient	Distribution of strength of the ties measured by the GINI coefficient applied to outdegree centrality. .

Table 11: Core-Periphery analysis

		Density of the linkages		Final fit
		Core	Periphery	
1972-1990	Core	9647.625	701.823	0.734
	Periphery	701.823	122.578	
1972-2001	Core	3807.023	223.129	0.828
	Periphery	223.129	35.78	
Total	Core	11786.04	2209.817	0.764
	Periphery	2209.817	148.525	

Table 12: Company in the core over time

	Company in the core
1972-1990	Fujitsu, Alcatel, Ericsson, Siemens, and ITT
1972-2001	Zhongxing, Alcatel, Ericsson, Lucent, Fujitsu, Siemens, Great Dragon, Huawei, Nortel, and ITT
Total	NEC, Alcatel, Lucent, Great Dragon, Siemens, Ericsson, Huawei, and GTE

Table 13: Alternative summary statistics

Company Alternative	**Cases Present**	**Frequency selected**	**Percent selected**	**Large**
Alcatel	775	135	16.92	x
Bosch	701	1	0.13	
Datang	68	0	0	
Ericsson	721	82	10.28	x
Fujitsu	664	25	3.13	x
HanWha	555	9	1.13	
Hitachi	687	0	0	
LG	478	6	0.75	
Lucent	488	74	9.27	x
GEC	582	6	0.75	
Mitel	663	18	2.26	
NEC	664	36	4.51	x
Nokia	786	66	8.27	x
Nortel	753	154	19.3	x
OKI	640	0	0	
Philips	554	4	0.5	
Samsung	473	33	4.14	x
Siemens	762	111	13.91	x
Teltronics	685	16	2.01	
Zhongxing	169	6	0.75	x
GTE	607	1	0.13	
GEC-Plessy	134	6	0.75	
ITT	697	9	1.13	